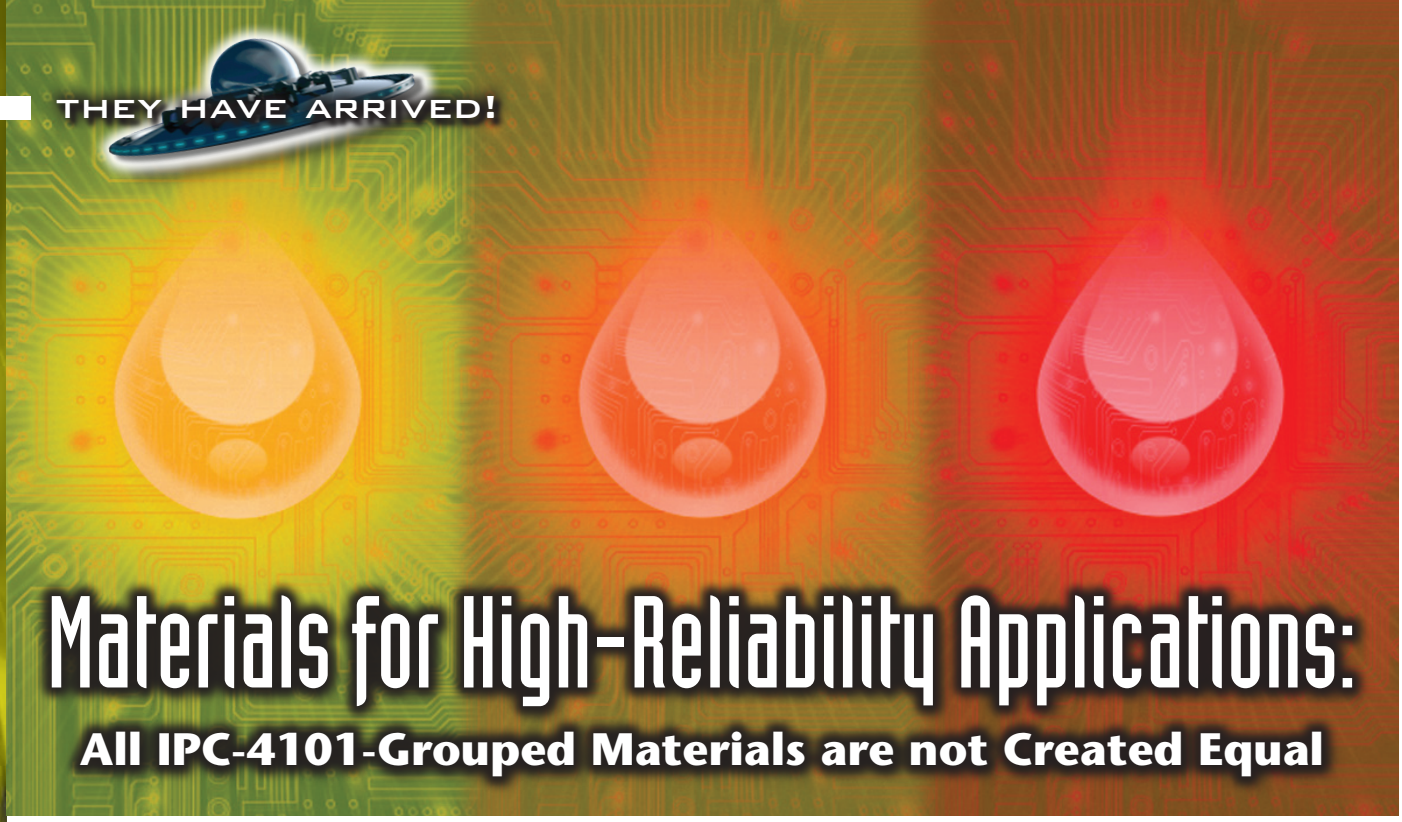

Materials for High-Reliability Applications:

All IPC-4101-Grouped Materials are not Created Equal

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SUMMARY

When discussing high-reliability materials for printed circuit board applications, the conversation typically gears towards opinions of reliability: is one material system versus another better? Other times, it's materials' properties that are stressed to imply reliability.

Materials Callouts

One commonly cited document is the IPC-4101C Specification for Base Materials for Rigid and Multilayer Printed Boards. This standard creates slash sheets, or "silos," to combine like materials based on meeting product or performance characteristics such as resin type or a minimum Glass Transition (T_g) rating. In recent years, new slash sheets have been created to address materials capable for lead-free assembly that incorporates Glass Decomposition Temperature (T_d).

For purposes of this discussion, we will focus on these lead-free capable materials. A summary table of three commonly called out standards is provided in Figure 1 for reference.

Once stacked next to each other, it's easy to see why one could infer reliability via higher-level IPC categories and/or underlying materials properties such as T_g or T_d. We argue, however, that these characteristics are almost meaningless when taken in a vacuum. They are merely indicators of the raw material, not the finished product, when it comes to reliability. Materials contribute only one part of a combination of systems that dictate the reliability of a product. In order to test the system, we have to undergo reliability testing.

Test Methods

Thanks to our industrious friends on the other side of the Great Wall, we've been pushed to diversify our customer base over the past decade away from our historical automotive supply base. This allowed us to experience a broad array of what people like to rely on for reliability testing. Industries we serve as a significant part of our business include Automotive, Military/Aerospace, Industrial Controls and Telecommunications.

Typically, the most intensive tests focus on via hole wall reliability. We'll review a few of the common ones below.

> *“MATERIALS CONTRIBUTE ONLY ONE PART OF A COMBINATION OF SYSTEMS THAT DICTATE THE RELIABILITY OF A PRODUCT.”*

	4101/99	4101/101	4101/126
Resin System			
Primary	Epoxy	Difunctional Epoxy	Epoxy
Secondary 1	Multifunctional Epoxy	Multifunctional Epoxy	Multifunctional Epoxy
Secondary 2	Modified Epoxy or Non-epoxy (max 5%)	Modified Epoxy or Non-epoxy (max 5%)	Modified Epoxy or Non-epoxy (max 5%)
Curing Agent	Not Specified	Not Specified	Not Specified
Fillers	Contains inorganic fillers	Contains inorganic fillers	Contains Inorganic Fillers
T_g	150 C min.	110 C min.	170 C min.
T_d	325 C min.	310 C min.	340 C min.
Z-Axis CTE			
Alpha 1	60 max	60 max	60 max
Alpha 2	300 max	300 max	300 max
50-260 C	3.5	4.0	3.0
T260 (min)	30 min	30 min	30 min
T288 (min)	5 min	5 min	15 min
T300 (min)	ABBUS	ABBUS	2 min

Figure 1: IPC-4101 Summary Table.

Delphi C7000

Delphi’s testing attempts to simulate real operating conditions of the PCB by applying temperature cycling to Daisy Chain coupons. Each coupon contains a series of vias linked to each other through plated vias and inner layer connections. The test qualifies the vendor based on layer count and min via diameter. Testing is performed using two air-to-air test chambers. Standard parameters are five minutes transition time between peak temperatures, and 25 to 30 minutes at peak temperatures. Measurements are performed five times during the process, which terminates at 1000 cycles. Needless to say, this is not a quick test.

Highly Accelerated Thermal Shock (“HATS”)

The HATS test simulates the C7000 testing requirements by using an air-to-air thermal cycling procedure that rapidly heats and cools the test vehicles to the min and max temperatures by using a single chamber and introducing heated and cooled air. The benefit of this method is that it requires approximately 1/6 to 1/7 the time required for the C7000 testing. However, there are schools of thought that believe this method is not as aggressive as the full thermal cycling required by Delphi’s testing.

Interconnect Stress Test (“IST”)

IST is another accelerated method of testing. Rather than use an air-to-air method to bring the test vehicles to temperature, this test method relies on an electrical charge to heat the coupon and stress the vias. To date, we are not aware of a direct correlation between this method and the previous air-to-air methods.

The main difference between these tests is how they attempt to stress the test vehicles. The main commonality is that they measure reliability based on resistance measurements of the daisy-chained vias.

Materials Comparison Testing

Before we discuss the reliability of one material over another, it’s critical to establish why a particular material may display better reliability testing results. Notice that the reliability test results are not of a particular

characteristic or measurement of the laminate itself, but rather a measurement of a feature created in the material—the via itself.

The fact that we are testing the vias for reliability means that we are not testing the material, but rather the effect of the material on various manufacturing processes, and vice versa.

The process/material combinations that have the most impact on these reliability tests are as follows:

DRILLING: Drilling parameters (feed, speed, retract, max hit count) must be optimized by resin system. Some systems are more abrasive against drill tools, while others are more brittle. Incorrect or non-optimum parameters can result in rough holes walls, gouges, incomplete de-smear and inter-connect defects, among others.

DESMEAR: Regardless of whether the fabricator uses plasma or permanganate methods, the process must be modified based on the resistance of each resin system. Cycles times may have to be increased if inefficient drill parameters result in excess smear across inner layer interconnects.

COPPER PLATING: Cycles to failure is often correlated directly with copper plating thickness. Rough holes can create turbulence during copper electroplating that has a negative effect on average plating thickness in the hole. Of course, plating a fine grain structure copper with high tensile strength and elongation properties is critical to increased life in a thermal cycling environment.

MATERIALS: Finally, there are the physical properties of the material itself. These include T_g, Td, CTE, among others. IPC-4101C uses these and other materials' properties to create classifications that are often used for product selection for particular applications.

In order to establish a difference in reliability between two resin systems, the proper method would require us to hold as many things constant between the two test procedures, such as:

Material Choice: We chose two materials that are qualified to the IPC-4101/126 slash sheet. Both have similar T_g and T_d values that are the most commonly called out characteristics in customer fabrication notes that we see as part of the normal course of business.

Test Vehicle: Eight-layer daisy chain coupon with finished hole sizes (in mils): 6, 8, 10, 12 and 14.

Resin System 1

	# of Test Vehicles Failed at Marked Endpoint				
FHS	0 Hr	336 Hr	504 Hr	750 Hr	1008 Hr
0.006	0	3	7	9	9
0.008	0	0	2	8	11
0.010	0	0	0	8	9
0.012	0	0	0	0	5
0.014	0	0	0	0	0

Resin System 2

	# of Test Vehicles Failed at Marked Endpoint				
FHS	0 Hr	336 Hr	504 Hr	750 Hr	1008 Hr
0.006	0	0	0	0	0
0.008	0	0	0	0	0
0.010	0	0	0	0	0
0.012	0	0	0	0	0
0.014	0	0	1	1	1

Figure 2: Failures recorded at test intermission points.

Quantity: 11 coupons per resin system.

Preconditioning: All coupons were passed six times through a lead-free reflow cycle.

Test parameters: -40°C to 120°C temperature range. Five minutes transition between extremes. Twenty-five minutes at temperature.

Test requirements: Endpoints of each daisy chain (one per hole size) are measured throughout the test at hours 0, 336, 504, 750 and 1,000. Hole size fails for qualification if any of the coupons show a change in resistance of more than 10%. Coupons that pass are cross-sectioned to validate no potential for latent failures exist, such as cracks in the copper plating.

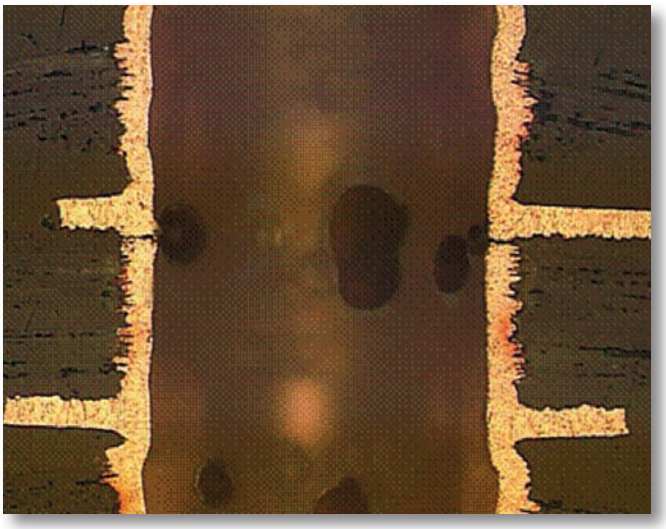


Figure 3: Barrel cracks due to Z-axis expansion.

Test results

As the charts display (Figure 2), there is a significant change in performance by changing the material type, but holding all other inputs constant (i.e., manufacturing process).

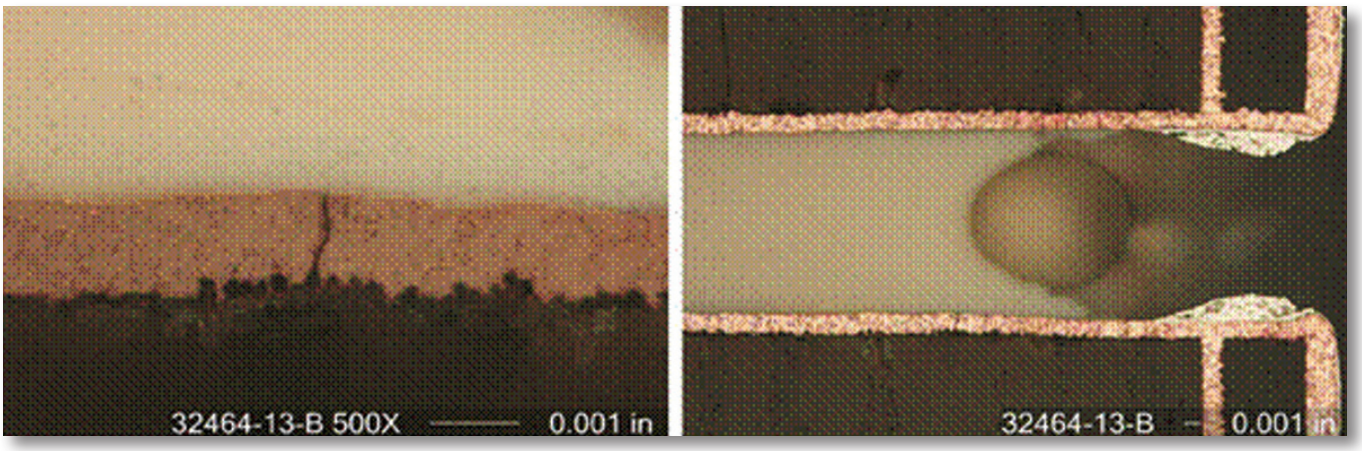


Figure 4: Stress Crack in Copper plating.

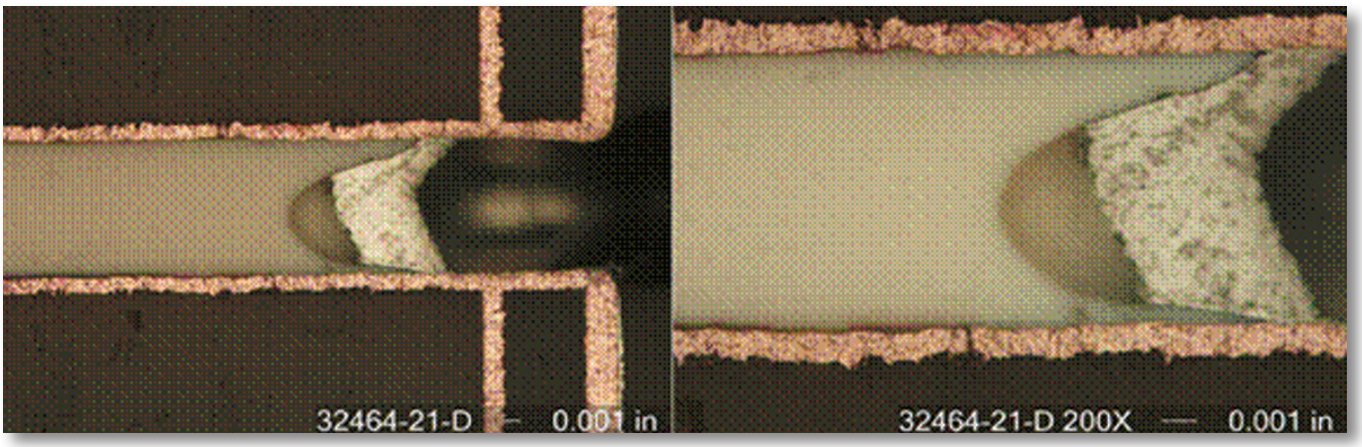


Figure 5: Stress Cracks in Copper plating.

Failure analysis

Failures in this test can include blistering and delamination, but are predominantly hole wall cracks or interconnect separations (Figures 3, 4 and 5).

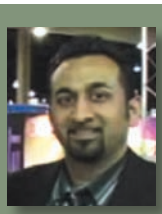
The thermal cycling causes the material to expand and contract in the Z-axis. As seen in the photos at left, this can cause hole wall failures if the expansion is too great compared to the ability of the copper plating in the hole wall to adjust accordingly.

Conclusion

When it comes to materials reliability, our first stop is typically and IPC-4101 category, or a specific material property, such as CTE, T_g or T_d. We have found that materials categorized into the same IPC slash sheet are not all equal.

Unfortunately, laminators trying to meet a particular value of a higher performance property can overlook other properties that sometimes are not found on a datasheet or IPC- 4101 listing. The benefits of those properties can be easily diminished if the material diminishes the performance of other processes such as drilling or plating.

If true reliability is of utmost concern, the PCB user must qualify not only the resin system, but also the entire system used to produce the PCB to ensure that the fabricator and laminate system are compatible. **PCB**



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